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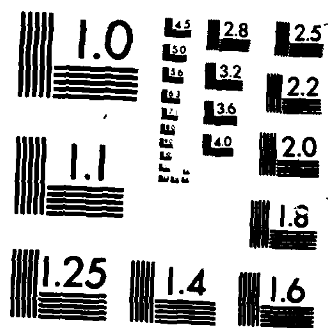

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APPLIED MARINE RESEARCH LABORATORY
OLD DOMINION UNIVERSITY
NORFOLK, VIRGINIA

TOXICITY TESTS OF THE SEDIMENTS FROM THE PORT OF HAMPTON ROADS: LETHAL EFFECTS

By

Raymond W. Alden, III, Ph.D.,
Principal Investigator

Robert J. Young, Co-Investigator

Supplemental Contract Report
For the period ending September 1984

Prepared for the
Department of the Army
Norfolk District, Corps of Engineers
Fort Norfolk, 803 Front Street
Norfolk, Virginia 23510

Under
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Work Order No. 0016

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All sediments meet EPA criteria for open ocean disposal except those in the lower reaches of the Southern Branch of the Elizabeth River. An interesting speculation of report is that maintenance dredging in the Southern Branch during the contract period apparently lowered the toxicity of the sediments as observed in the solid phase bioassays.

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APPLIED MARINE RESEARCH LABORATORY
OLD DOMINION UNIVERSITY
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October 1984

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TOXICITY TESTS OF THE SEDIMENTS FROM THE PORT OF HAMPTON ROADS: LETHAL EFFECTS

By

*Raymond W. Alden, III and
Robert J. Young

INTRODUCTION

A great deal of attention has been focused recently upon the possibility of open ocean disposal of dredged materials. In order for open ocean disposal to be an environmentally sound alternative to containment or upland options, the potential ecological impact at each site must be assessed. The U.S. Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers (COE) have done extensive work in developing criteria by which the potential environmental impact of open ocean disposal can be assessed on a site-specific basis (Lee and Plumb, 1974; Lee _et al_., 1975; EPA, 1976, 1978; Hirsch _et al_., 1978; Pequegnat _et al_., 1977, 1978; and others). The final criteria for the assessment of materials destined for ocean disposal have been specified in the Federal Register (Jan. 11, 1977) and an implementation manual (EPA/COE, 1978) provides the technical guidelines for evaluating the ecological effects of dredged material disposal. These guidelines describe a series of lethal bioassays which are designed to evaluate the acute toxicity of sediments in order to minimize or prevent severe damage to open ocean ecosystems.

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~~The present study~~ represents a portion of a program designed to assess the potential environmental impact of open ocean disposal of sediments from Norfolk District COE dredging sites in Chesapeake Bay, Hampton Roads Harbor and the Elizabeth River. Sediments from representative sites throughout the seaport system were evaluated through a series of lethal bioassays designed to test the acute toxicity of the suspended solid and solid phase sediment fractions.

METHODS AND MATERIALS

Study Area

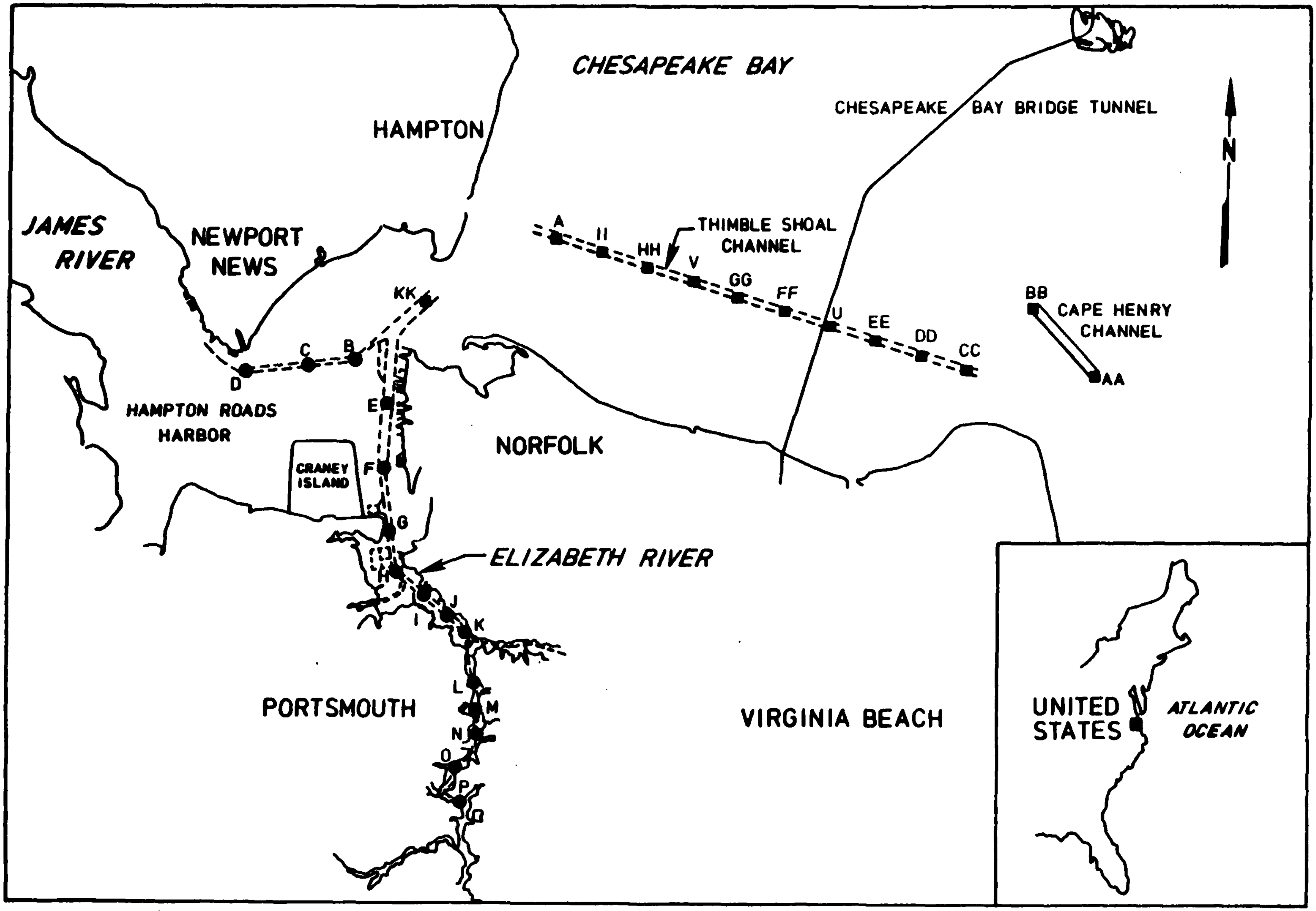
The Port of Hampton Roads, Virginia, among the largest natural harbors in the world, is located within a major metropolitan area that includes the cities of Norfolk, Virginia Beach, Chesapeake, Portsmouth, Newport News, and Hampton (Fig. 1a). Hampton Roads and the surrounding estuarine systems contain one of the most highly industrialized coastal areas on the eastern seaboard of the United States, as well as the largest military port in the world. The Norfolk District COE is responsible for maintaining the navigation channels of this seaport system in order to insure the safe passage of military and commercial vessels. On the average, 4.1×10^6 m^3 of sediment are dredged annually by the COE. Approximately 60% of the sediment are classified as mud, clay and silt, taken primarily from the highly industrialized Hampton Roads Harbor/Elizabeth River complex. The remainder consisting of sand, gravel and shell is dredged mainly from channels in Chesapeake Bay (Pequegnat et al., 1978).

Currently, the sediments from Hampton Roads are being disposed at Craney Island, a confined disposal site. Unfortunately, the current configuration of this facility is expected to be filled to capacity through routine maintenance dredging and disposal operations in the relatively near future. Therefore, open ocean disposal of dredged materials meeting the criteria, coupled with the effective management of the Craney Island facility for

disposal of sediments deemed "unacceptable for ocean disposal," appears to be the most attractive alternative. The urgency for the assessment of this alternative is compounded by the fact that plans are being made to deepen the Port of Hampton Roads from 13.8m to 17m to accommodate shipping industries utilizing larger, deep-draft vessels. Therefore, the filling of Craney Island will be accelerated if disposal operations remain _status quo_. This present study addresses the question of which materials would be acceptable for ocean disposal by evaluating the relative toxicity of sediments according to EPA/COE technical guidance.

Sediments for the lethal bioassay experiments were collected from numerous stations throughout the Port of Hampton Roads. Detailed descriptions of the major collection areas have been presented previously (Alden _et al_., 1981, 1982). Since previous studies (Alden _et al_., 1981; Alden and Young, 1982) have shown the suspended solid phase of sediments from Stations K and M in the Southern Branch of the Elizabeth River to be extremely lethal to the shrimp, _Palaemonetes pugio_, a new series of tests was initiated in 1982 to delineate the toxicity of sediments from the surrounding areas. Sediments from Stations I, J. J/K (located between J and K) N, N/O (located between N and O) O, O/P (located between O and P), P, Q, and R were tested with a "screening" suspended solid phase bioassay using the same species (Fib. 1b). These "screening" tests employed only the 100% concentration of the elutriates rather than a full dilution series described by EPA/COE (1978).

Figure 1a. Study area for the lethal effects of sediments from the Port of Hampton Roads: the Lower Chesapeake Bay.



CHESAPEAKE BAY
CHESAPEAKE BAY BRIDGE TUNNEL
N
HAMPTON
JAMES RIVER
NEWPORT NEWS
THIMBLE SHOAL CHANNEL
A
II
HH
V
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CC
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CAPE HENRY CHANNEL
AA
KK
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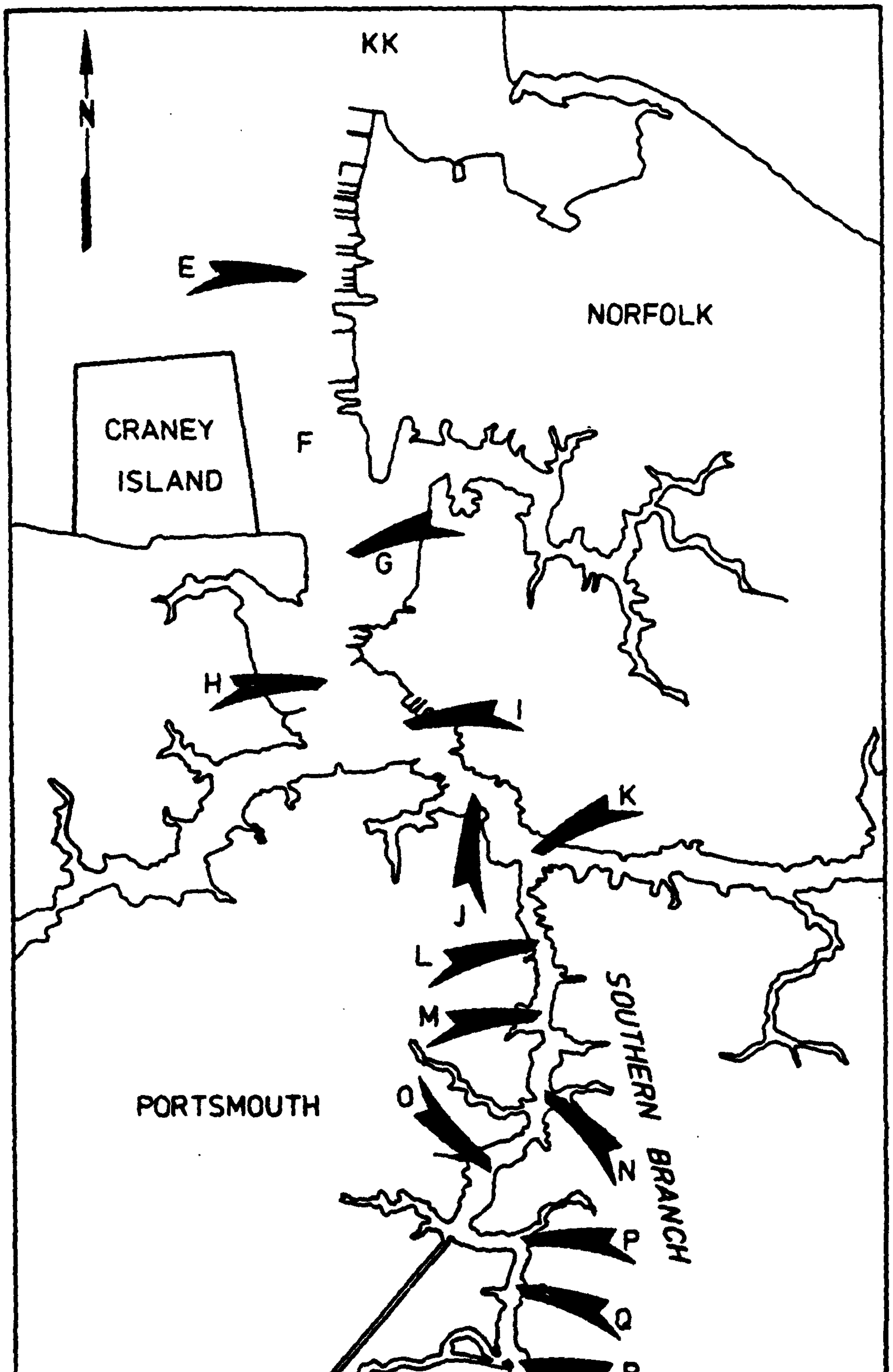
P
Q
HAMPTON ROADS HARBOR
NORFOLK
CRANEY ISLAND
ELIZABETH RIVER
PORTSMOUTH
VIRGINIA BEACH
UNITED STATES
ATLANTIC OCEAN

Figure 1b. Study area for the lethal effects of sediments from the Port of Hampton Roads: the Southern Branch of the Elizabeth River.


N
KK
NORFOLK
E
CRANEY
ISLAND
F
G
H
I
K
J
L
M
SOUTHERN BRANCH
PORTSMOUTH
O
N
P
Q
R
S

The evaluation of the "worst case" situation allowed a number of stations to be tested simultaneously. During the same period, screening suspended solid bioassays were conducted on sediments composited to a depth of 3m from representative stations throughout the Port: Stations D, E, H and P. During 1983, complementary screening suspended solid phase tests were conducted on *P. pugio* and on the sheepshead minnow, *Cyprinodon variegatus* evaluating sediments from Stations D, KK, E, F, H and J.

An extensive series of 10-day solid phase bioassays was also conducted. Experiments utilized *P. pugio*, the hard clam, *Mercenaria mercenaria*, and the sand worm, *Nereis virens*. Test sediments were collected from a number of Stations: KK, D, E, F, G, H, I, J, K, L, M, N, O, P, Q, R and S; as well as composites from Stations AA and BB in Cape Henry Channel (designated CH), Stations CC, DD, EE and U in the outer reaches of Thimble Shoals Channels (designated TSO), and Stations FF, GG, HH, V, II, and JJ in the inner regions of the Thimble Shoals Channel TSI). The blue mussel, *Mytilus edulis*, was used as a bioaccumulation indicator in solid phase bioassays of sediments from the Southern Branch of the Elizabeth River (Stations K through S) and the access channels (CH, TSI and TSO). In addition to the solid phase bioassays, mortalities of shrimp were monitored in a bioaccumulation experiment conducted in 1981 to determine the potential contamination of test organisms by Kepone when exposed to sediments from throughout the Port: D, E, H, I, J, K, N, O, P, Q, R (Figure 1a and b).

Sediments were collected at each of the stations by a $0.76m^3$ capacity clamshell grab or a 20 l stainless steel Pearce bucket dredge. The sediments in the central portion of the bucket were scooped in 18 l snap-top polyethylene containers and stored at 4^oC until bioassayed.

Bioassay Methods

Each lethal bioassay experiment followed the guidelines established by the Implementation Manual (EPA/COE, 1978). The test species *P. pugio*, *M. mercenaria*, *N. virens*, *C. variegatus* and *M. edulis* were recommended as being representive test organisms for dredged material bioassays. The shrimp and mussels were collected in non-industrialized areas, while the remaining species were purchased from a commercial firm specializing in culturing bioassay organisms. The test species were gradually acclimated to 20^oC temperature and 30 ppt salinity, the standard temperature and salinity regime recommended for the North Atlantic EPA regions (EPA/COE, 1978). No animals were acclimated for less than four days or more than two weeks prior to testing. All experiments were conducted in acid-washed 30 l aquaria. Oxygen concentration in the bioassay and culture aquaria was monitored and aeration was supplied when levels dropped below 4 ppm.

The suspended solid phase bioassays were 96-hour acute toxicity experiments of the fine suspended materials associated with disposal. The sediments were elutriated by vigorously agitating a 1:4 (v/v) mixture of the materials in artificial seawater by compressed air for 30 min. The resulting suspension was allowed to settle for one hour and the supernatant (i.e. the 100%

eltriate) was pumped into the aquaria for testing. Three replicates were established for each station, with 10 (C. variegatus) or 20 (P. pugio, M. mercenaria, N. virens and M. edulis) test organisms per aquarium.

Solid phase bioassays were 10 day experiments. Prior to each bioassay, the organisms were acclimated to reference sediments taken from the proposed Norfolk Disposal Site (NDS). Reference sediments were introduced into each aquarium to a depth of 30mm and the organisms were acclimated for 48 hours prior to exposure to the sediments. At the beginning of the bioassays, sediments from the various sites were introduced into the aquaria to provide a uniform 15mm layer. The control organisms were exposed to the introduction of an additional 15mm layer of reference sediments. Five replicates were established for each experimental or control treatment. Seventy-five percent of the water in the aquaria was replaced with artificial seawater after 1 hour and 24 hours during the acclimation period at hours 1, 48, 96, 144 and 192 during the bioassays.

The experimental and control percent mortality data were arcsine transformed to normalize the data sets. The homogeneity of variances were then tested with a Cochran's C-test. The data were then analyzed by Analysis of Variance (ANOVA) to determine whether significant ($\alpha = 0.05$) differences in mortality values could be detected between treatments of each bioassay series. When significant differences were detected, a Duncan's Multiple Range test was employed to determine which of the experimental

conditions produced mortalities that were significantly higher than the control values.

RESULTS

The results of the suspended solid screening bioassays are presented in Table 1. During the 1980 series of bioassays, the suspended solid elutriates from Stations K and M in the Southern Branch of the Elizabeth River proved to be toxic to shrimp (Alden et al., 1981; Alden and Young, 1982). Mortalities of the test organisms occurred within the first four hours of the experiment. In contract, exposure to the elutriates of sediments from the other stations evaluated during the present study did not produce extremely high mortalities in the grass shrimp populations. Mortalities of shrimp exposed to elutriates from Stations N/O and O were significantly higher than the controls, but the absolute levels of mortalities were quite low (less than 12%). The mortalities of shrimp from the remaining experiments were not significantly greater than the controls. Absolute mortality values were particularly low for shrimp exposed to elutriates from the stations on the main stem of the Elizabeth River. Fish exposed to elutriates from these stations experienced few mortalities.

The mortality data from the 10-day solid phase bioassays are presented in Table 2. The controls of all species exhibited low mortalities. In experiments where shrimp were exposed to sediments from the stations in the Southern Branch of the Elizabeth River, mortalities were significantly elevated over

TABLE 1

Mean mortalities (standard errors in parenthesis) observed following 96-hour suspended solid phase bioassays. Asterisks indicate mortalities shown by Duncan's test to be significantly higher than control values.

Station	Mortality of Test Species *P. pugio*	*C. variegatus*
Control (grand mean)	2.2 (1.5)	0
KK	6.6 (4.4)	3.3 (3.3)
D	1.7 (1.7)	0
D (3m)	0	0
E	3.3 (1.7)	0
E (3m)	0	0
F	8.3 (4.4)	3.3 (3.3)
G	0	-
H	1.7 (1.7)	0
H (3m)	0	0
I	0	-
J	1.7 (1.7)	0
J/K	5.0 (2.9)	-
K (1980)	50.0 (5.0)*	-
M (1980)	90.0 (10.0)*	-
N	8.3 (1.7)	-
N/O	11.7 (1.7)*	-
O	11.7 (1.7)*	-
O/P	5.0 (2.9)	-
P	1.7 (1.7)	-
P (3m)	0	0
Q	8.3 (3.3)	-
R	8.3 (6.0)	-

Note (3m) = Experiments testing sediments composited down to a depth of 3m.

TABLE 2

Mean mortalities (standard errors in parenthesis) observed following 10-day solid phase bioassays. Asterisks indicate mortalities shown by Duncan's test to be significantly higher than control values:

Station	Mortality of Test Species			
	P. pugio	*M. mercenaria*	*N. virens*	*M. edulis*
Control (grand mean)	4.6 (1.4)	2.0 (1.2)	6.0 (4.0)	0
CH	0	0	0	0
TSO	0	0	0	0
TSI	1.1 (1.1)	0	0	0
KK	1.6 (1.0)	2.0 (1.2)	2.0 (2.0)	-
D (1981)	5.6 (5.6)	-	-	-
D	12.0 (1.2)	2.0 (1.2)	4.0 (4.0)	-
D (3m)	2.5 (2.5)	0	-	-
E (1981)	12.6 (4.8)	-	-	-
E	12.0 (2.0)	0	2.0 (2.0)	-
E (3m)	3.3 (1.2)	0	-	-
F	3.2 (1.5)	0	4.0 (2.5)	-
G	11.0 (1.1)	2.0 (2.0)	6.7 (6.7)	0
H (1981)	11.1 (4.5)	-	-	-
H	14.4 (6.0)	2.0 (2.0)	6.0 (5.8)	-
H (3m)	10.3 (3.2)	0	-	-
I (1981)	20.0 (3.3)	-	-	-
I	14.7 (7.3)	0	2.0 (2.0)	-
J (1981)	42.2 (1.1)*	-	-	-
J	5.3 (3.5)	1.0 (1.0)	10.0 (4.9)	-
K (1981)	40.0 (1.9)*	-	-	-
K	30.0 (8.0)*	2.7 (2.7)	10.0 (5.8)	0
L	20.0 (3.3)*	2.7 (2.7)	3.3 (2.1)	0
M	35.0 (10.0)*	4.0 (2.7)	10.0 (5.8)	0
N (1981)	41.1 (3.9)*	-	-	-
N	18.0 (1.1)*	2.7 (2.7)	16.7 (8.6)	5.3 (5.3)
O (1981)	67.8 (2.2)*	-	-	-
O	47.6 (7.8)*	40.3 (2.0)*	18.0 (8.7)	10.7 (7.1)
P (1981)	28.9 (8.9)*	-	-	-
P	17.8 (2.9)*	0	0	5.3 (5.3)
P (3m)	12.3 (3.0)	0	-	-
Q (1981)	17.8 (1.1)	-	-	-
Q	14.4 (4.5)*	1.3 (0.7)	6.7 (6.7)	2.7 (2.7)
R (1981)	16.7 (1.9)	-	-	-
R	20.0 (5.8)*	1.3 (1.3)	6.7 (6.7)	2.7 (2.7)
S	10.0 (3.9)	0	0	5.3 (5.3)

Notes (3m) = Experiments testing sediments composited down to a depth of 3m.
(1981) = Mortalities in the summer 1981 Kepone bioaccumulation experiments *P. pugio*.

that of the controls. The shrimp mortalities reached a peak for Station O sediments (68%), with moderate values (20-40%) being found for the surrounding regions. None of the other exposures to the sediment fractions produced significantly elevated mortalities for shrimp. Therefore, the sediments from the Chesapeake Bay access channels, the Hampton Roads Harbor, the main stem of the Elizabeth River and the upper reaches (Stations Q, R and S) of the Southern Branch did not produce significant lethal effects. The mortalities of shrimp exposed to sediments composited to a depth of 3m (Stations D, E, H and P) were consistently lower than those exposed to surface sediments from the same stations.

The hard clam exhibited uniformly low mortalities for all stations except one: (Table 2). The mortalities of the clams exposed to sediments composited over depth (Stations D, E, H and P) were zero. The mortalities of the worms and the mussels were quite low, never significantly higher than those observed for the controls.

DISCUSSION

Several major patterns can be derived from the data. First, the grass shrimp appears to be the most sensitive of all species tested. These findings support earlier contentions concerning the sensitivity of the species and its appropriate use as a standard bioassay test organism (Lee et al., 1977; Gentile, 1980). The other test species (*M. mercenaria*, *N. virens*, *M. edulis* and *C. variegatus*) exhibited much lower mortalities, despite the fact that the infaunal clams and worms were more directly exposed to the sediments than the epibenthic shrimp.

The suspended solid phase bioassays with the shrimp were used to screen the relative toxicity of sediments from numerous stations throughout the Port. Only a few of the sediment elutriates tested were shown to be associated with toxicity. However, those stations which were shown to be associated with significant mortalities were all found in the same highly industrialized section of the Southern Branch of the Elizabeth River between Stations K and O.

Early studies on dredged material toxicity (Hoss et al., 1974; and DeCoursey and Vernberg, 1975) reported significant lethal effects to be associated with exposure of test organisms to extracts of sediments from a number of sites in an industrialized seaport. However, more recent studies from a variety of seaport systems have indicated that acute toxicity of fractions from dredged materials appears to be the exception, rather than the rule (Lee and Jones, 1977; Lee et al., 1977; Lee et al., 1978; Hirsch et

al., 1978). The low degree of toxicity observed in the more recent studies may be due to new elutriation procedures which include the mixing of sediments and seawater with compressed air.

Many of the potential toxins commonly observed in sediments appear to exhibit low bioavailability under the oxidizing conditions typically found at open ocean disposal sites (Lee et al., 1978). The data from the present study reflects the same low degree of toxicity from the majority of the stations in the Port of Hampton Roads. Perhaps the fairly rare occurrence of toxicity of dredged material elutriates should generate greater concern for stations containing sediments actually producing lethal effects in suspended solids tests. Therefore, the sediments of the lower reaches of the Southern Branch of the Elizabeth River (i.e. in the region of Stations K through O) might be regarded with concern in terms of open ocean disposal options, despite the fact that they might meet the specific ocean disposal criteria when dilution in the mixing zone is considered (Alden et al., 1981; Alden and Young, 1982). On the other hand, sediment elutriates from Hampton Roads Harbor, the main stem of the Elizabeth River and the upper reaches of the Southern Branch do not appear to be toxic to the shrimp. The fish bioassays confirmed the lack of toxicity for harbor/main stem region.

The 10-day solid phase bioassays with the shrimp confirmed that the region of sediment toxicity is restricted to the Southern Branch. Significant mortalities extended between Stations K and R, with maximum values found for Stations M and O. The hard clam

mortalities were also significantly elevated when exposed to Station O sediments, but values for other sediments were quite low.

It is often difficult to pinpoint specific toxic agents which may be primarily responsible for observed lethal effects in dredged material studies. In fact, the results of previous studies have seldom found a correlation between apparent toxicity and bulk contamination of the sediments (Hirsch et al., 1978). It is interesting to note, however, that the region identified as containing sediments with the greatest toxicity is also the most industrialized area of the Port. This region is reported to be contaminated with both heavy metals (EPA 1976b; Alden et al., 1981) and organic toxins (VSWCB, 1984; Alden et al., 1984). Although no cause and effect relationships can be drawn between specific pollutants and the toxicity of the sediments, there does appear to be an overall association between the degree of lethal effects and the relative contamination of the sediments in this heavily industrialized region.

The present study makes an additional contrast between the relative toxicity of the suspended solid and solid fractions of the sediments in the same region. The bioassays using sediments from Stations K and M in 1980 indicated that much of the lethality of the sediments was associated with the suspended solid fractions, with only moderate mortalities being recorded for shrimp exposed to the solid phase (Alden et al., 1981; Alden and Young, 1982.) During the present study, the suspended solid elutriates produced only moderately low mortalities for this

region while the solid phase tests produced higher, but quite moderate values (generally 20-40%, up to 68%).

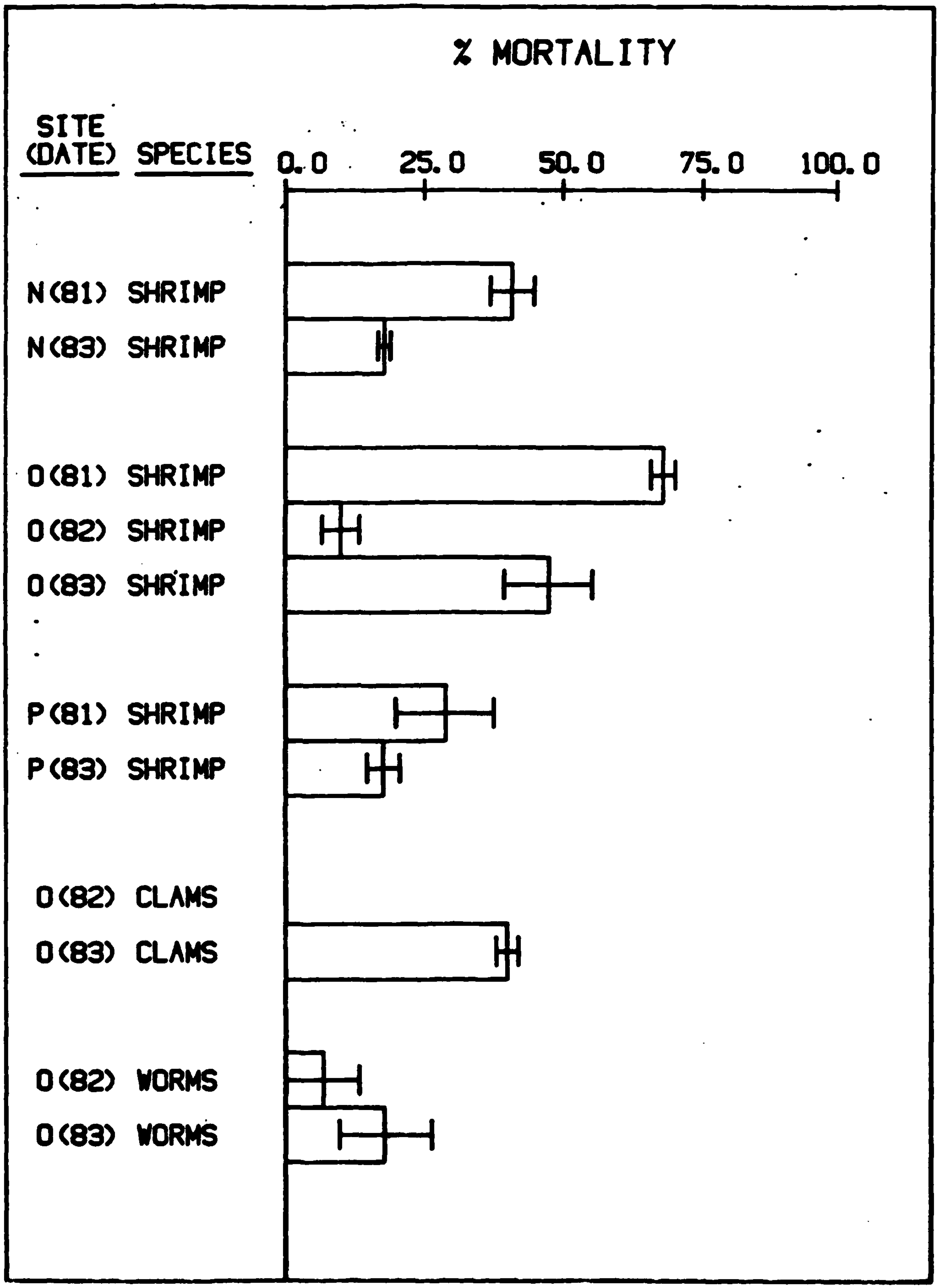
One explanation of the differences between the studies in the relative lethality of the fractions is the fact that maintenance dredging operations took place in the Southern Branch of the Elizabeth River during the fall of 1982 and the screening suspended solid phase bioassays were conducted during the spring of 1982. Therefore, much of the toxic sediments in the channel may have been removed by dredging between the 1980 and 1982 suspended solid bioassays. On the other hand, the solid phase bioassays were conducted during the late spring and summer of 1983, over 18 months after the dredging, and the toxicity of the solid fractions of the sediments approached the levels found in 1980 and 1981. It appears that contamination from the numerous nonpoint sources in the region and/or slumping of contaminated sediments from the sides of the channels had increased the toxicity of the sediments during the post-dredging period.

The apparent loss of toxicity following dredging operations is presented in Figure 2. The 1981 and 1983 data are from the bioaccumulation and solid phase bioassays (Table 2), while the 1982 data were from a microcosm-bioassay experiment testing sediments from Station 0. In all cases, the mortalities from experiments conducted during the summer of 1981 were highest, followed by those observed in 1983. The 1982 mortalities were the lowest. Thus, it appears that mortalities observed prior to dredging in 1981 disappeared in the single 1982 experiment, but

returned to a moderate degree in 1983. The differences between the 1981 and 1983 shrimp mortalities were greatest for the stations known to be in the region of the dredging project (Stations N, O, P; Table 2). Perhaps if the suspended solid tests had been conducted again in 1983, the fine fractions may have again exhibited the high degree of toxicity observed in 1980.

The most important finding of the present study is that most of the sediments in the Port would appear to be nontoxic and potentially acceptable for ocean disposal. The stations from the Chesapeake Bay access channels, the Hampton Roads Harbor, the main stem of the Elizabeth River and even the upper reaches of the

Figure 2. Comparison of mortalities of test species exposed to sediments from Stations N, O and P: 1981 Kepone bio-accumulation experiments; 1982 bio-assay - microcosm experiment (site O); and 1983 solid phase bioassays.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Southern Branch of the Elizabeth River all contained sediments which produced low or no mortalities of the test species. The experiments testing sediments composited to a depth of 3m indicated that the deeper sediments were, if anything, somewhat less toxic than the fairly innocuous surface materials. This trend would seem to confirm speculations previously discussed concerning the effects of maintenance dredging on reducing the toxicity of the sediments when the top layer of contaminated materials were removed. Therefore, the mixture of dredged materials produced by harbor deepening operations would be expected to be less contaminated than those routinely taken during the maintenance dredging operations.

SUMMARY AND CONCLUSIONS

An extensive series of toxicity tests were conducted on sediments from stations throughout the Port of Hampton Roads, Virginia. The grass shrimp proved to be a much more sensitive indicator of toxicity than the other test species: the hard clam, the sand worm, the blue mussel and the sheepshead minnow. Both the suspended solid and solid phase tests indicated that sediments from most of the navigational channels within the Port would meet ocean disposal criteria for toxicity. The sediments from Cape Henry Channel, Thimble Shoals Channel, Hampton Roads Harbor, the main stem of the Elizabeth River, and the upper reaches of the Southern Branch of the Elizabeth River contained sediments which proved to be nontoxic.

Significant lethal effects were observed for shrimp, and to a lesser extent, clams exposed to sediment fractions from the most industrialized area of the Southern Branch of the Elizabeth River. Unlike the findings of previous bioassays in the region, the suspended solid phase experiments produced lower mortalities than the longer solid phase experiments. It is speculated that maintenance dredging in the Southern Branch lowered the toxicity of the sediments during the suspended solid phase experiments. However, toxicity of the solid phase of the sediments of the region appeared to return to the level observed for the 1980 experiments 18-20 months following the dredging. Considering the fact that toxicity of dredged materials is the exception rather than the rule for most previous studies, the significant lethal

effects observed for these bioassays, regardless of magnitude, should make this region suspect. Therefore, it is suggested that the sediments from a 8-11 km reach of the Southern Branch of the Elizabeth River not be considered for ocean disposal.

The experiments evaluating the sediments composited to a depth of 3m indicate that these materials are less toxic than the surface sediments. Coupled with the observations of the apparent effects of maintenance dredging on toxicity, these findings indicate that the deepening operations should produce dredged materials less contaminated than those routinely taken by maintenance dredging operations in the same areas.

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